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Silvopastoral Systems in Southern South America

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Silvopastoral Systems in the Cold Zone of Brazil

10

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Abstract

The cold zone of Brazil occupies approximately 6 % of the national territory and is located between latitudes 24° S and 33° S. In this area, extensive cattle and sheep farming systems and conventional cropping and forestry are predominant. With the end of government subsidies by the decade of 1980s, an increase in farming production costs, a decrease of native forest covering, an increase of degraded areas in agriculture and livestock farming systems and a mismatch between timber national supply and demand after 1990s, an opportunity arises for integrate forestry with livestock and agriculture activities in Brazil, particularly in the southern. This chapter initially reports key events over the last three decades that have supported the increasing interest of farmers and enterprises on agroforestry activities, with focus on silvopastoral systems in the cold area of Brazil. Then, relevant advances on silvopastoral systems from research and extension services were reported, highlighting the screening of shaded adapted forage plants and management, trees species screening for silvipastoral systems and animal performance and behaviour under trees.

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Finally, the chapter analyses the existent opportunities to increase silvopastoral areas in southern Brazil and future challenges for research, development and technology transfer.

Keywords
Southern Brazil • Agroforestry • Tree • Forage • Cattle • Sheep

10.1 Introduction

The “cold zone” in Brazil is located in the southern region of the country, between latitudes 24° S and 33° S, comprising the states of Rio Grande do Sul, Santa Catarina and the south-central region of Paraná, occupying an area of approximately 576,410 km^2 (6 % of the national territory). This region has two important Biomes: the Pampa located at the most southern part of Rio Grande do Sul and the Atlantic Forest in southern Brazil territory. The climate is classified as subtropical cold with frequent frosts in winter and hot summers. Average annual temperatures range from 12 to 20 °C with well-defined seasons, and the annual average rainfall varies from 1250 to 2000 mm well distributed throughout the year. In the cold zones of Brazil, adaptation to frosts is the most important plant survival factor. As the frosts may vary each year (Fig. 10.1), the time of occurrence of frosts is critically important with regard to development of vegetation. The most damaging are early frosts in autumn and late spring. They eventually reach plants that are not cold hardy. In southern Brazil, 200,355 km^2 are arable land, 48,430 km^2 cultivated pastures, 108,426 km^2 grasslands, 62,088 km^2 natural forests and 25,313 km^2 tree plantations. Of the total arable land, 87 % is being used in row crop agriculture (i.e. soybean, maize and rice mainly) and 10 % is devoted to fruits and horticulture and 3 % to cutting forages (IBGE 2006).

Brazil has the second largest forest cover in the world, equivalent to 14.5 % of the global forest area, surpassed only by Russia (FAO 2014). Out of the total area of the country (845.7 M ha = million ha), approximately 54.4 % are covered by native forest and only 0.8 % with plantations. Planted forests in Brazil occupy approximately 7.2 M ha, of which about 5.1 M ha are eucalyptus, 1.6 M ha pines, and 0.5 M ha other species (ABRAF 2010). According to the Brazilian Association of Planted Forest Producers (ABRAF), the southern region currently has 1.9 million ha of eucalyptus (*Eucalyptus* spp.), pine (*Pinus* spp.), and black wattle (*Acacia mearnsii*) plantations and 511,000 ha of agroforestry areas (IBGE 2006). Among the main products of the national forest industry, the cold region of Brazil has a great emphasis on the production of yerba mate (*Ilex paraguariensis*), firewood, sawmill logs and wood for the panel, pulp and paper industries, besides the black wattle bark for tannin extraction.

This puts Brazil in a strategic position in global environmental issues due to the great productive potential of timber and non-timber forest products. From 1967 to 1987, reforestation programs with tax incentives resulted in a staggering growth in the sector, allowing organization of activities and consolidation of the forest sector as of great importance to the country. Investments, which totaled about US$ 10 billion, according to the Brazilian Ministry of Environment (MMA), resulted in a surplus in the supply of wood during this period, as a result of significant technological development attained by the planted forest sector, raising productivity in plantations of pine and eucalyptus from 20 to 40 m^3 per hectare per year.

With the end of tax incentives in 1987, there was a drastic reduction in forest plantations, compromising the expansion of the sector and leading to a mismatch between timber supply and demand to meet the needs of projected growth by forest-based industry in the medium and long term. According to estimations of the Federal Government agencies and the Brazilian Society of Silviculture (SBS), Brazil will need about 275

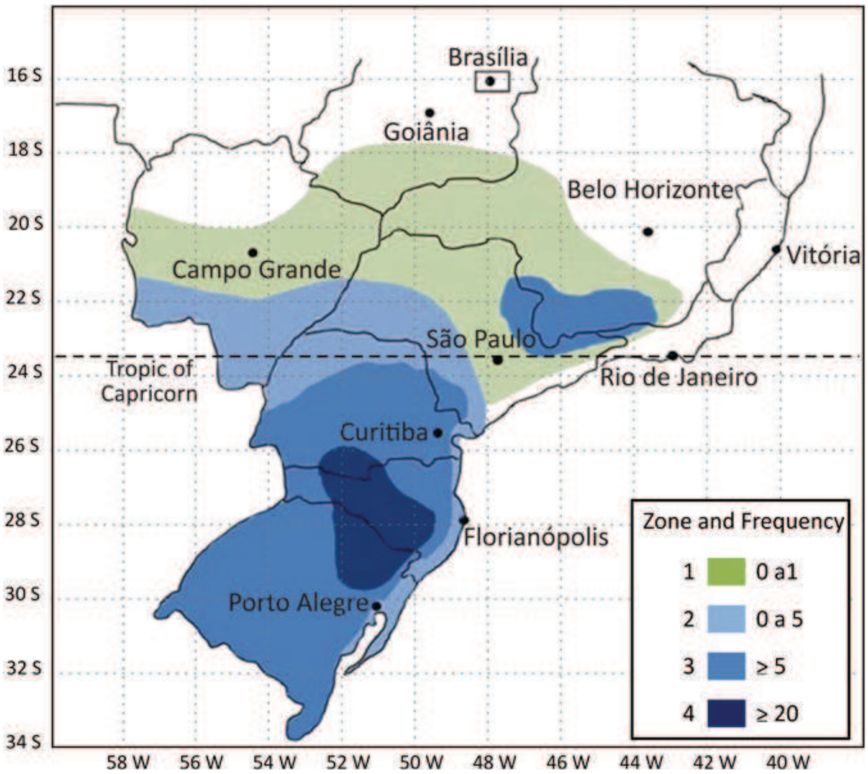

Fig. 10.1 Cold zones and frequency of frosts in southern Brazil. Data are from historical averages (Adapted from Sentelhas and Angelocci 2012)

million m^3 of wood from planted forests by 2020 to meet the national demands of the pulp and paper, lumber, panels, charcoal and firewood industries. This means an estimated area of 8.7 M ha to reach future demand of wood in the country by 2020, according to SBS (2008) and MMA. As southern Brazil concentrates 33 % of the national forest planted forests, then RS, SC and PR states would need to increase from current 1.9 M ha (IBGE 2006) to 2.9 M ha by 2020 or about 71,000 ha per year from 2006 to 2020. The scenario also pointed out a marked imbalance between supply and demand, with imminent risk of a deficit in wood supply and negative consequences to primarily sawmills and the furniture industry. The crisis of wood from commercial forests, known as a national "forest blackout," strongly affected the forest industries. Therefore, since 2004, government new incentives through extensive credit and low interest rates were offered and a new cycle of expansion for planted forests occurred mainly with eucalyptus for the pulp and paper industries and pine for sawmill lumber and veneer in southern Brazil. Due to the favorable climate and soils, the high productive potential, the existence of high-tech production tools, the availability of land at a low acquisition cost and the simultaneous crisis of livestock and agricultural sectors in the early 2000s, national and international companies and producers increased the area of plantations by approximately 331,000 ha in the last 5 years, mainly with eucalyptus and black wattle on the border area with Uruguay, and pine in highland areas of the states of Rio Grande do Sul and Santa Catarina.

From the early 1990s, the increase in production costs (especially agricultural inputs), a decrease of native forest cover, an increase of degraded areas mainly through soil erosion consequent to an increase in agricultural activities and livestock operations, and the phenomenon of rural exodus and concerns about animal welfare, led to the search for new and more sustainable production systems in southern Brazil, particularly involving the integration of forestry with agriculture and livestock systems. As a result, the first agroforestry systems were initiated in southern Brazil. According to Radomski and Ribaski (2010), Paraná was the first State to use silvopastoral systems to any great extent, mainly on beef cattle farms. The Grevillea tree (*Grevillea robusta*) and species of Eucalyptus and Corymbia (*Corymbia citriodora*) represented the most common forest species identified in these systems. Associations between Eucalyptus and Grevillea with native trees such as Canafistula (*Peltophorum dubium*), Gurucaia (*Parapiptadenia rigida*), Guabiroba (*Campomanesia* sp.), Aroeira (*Schinus terebinthifolius*) and the Yellow Ipe (*Tabebuia vellosoi*) were also observed.

In the early 1990s, technical work involving agroforestry systems in the cold region of Brazil was begun, mainly from collaboration between research teams of Embrapa (the Brazilian Research Corporation), federal universities, southern states research institutes and the rural extension and technical assistance organizations. Also in the 1990s, several undergraduate and graduate courses such as Forestry, Agronomy, Animal Husbandry and Veterinary Science, as well as polytechnics and technical schools included in their academic curricula knowledge and training on agroforestry systems. In addition, between 1980 and 1994, 76 technical and scientific articles were published by workers at the southern research institutes, of which 70 % were on agrosilvicultural systems and 30 % on silvopastoral systems (Montoya et al. 1994). Also in the 1990s, the first Theses and Dissertations on agroforestry systems from federal universities in southern Brazil were published, allowing the formation of new knowledge and specialized human resources in this area.

Also since 2000, the technical and scientific experiences in agroforestry systems have multiplied in southern Brazil, especially with the work of scientists at Embrapa National Forestry Center (CNPF) and Sheep and Animal Husbandry Southern Center (CPPSUL), the Federal Universities of Rio Grande do Sul (UFRGS) and Paraná (UFPR), the Agricultural Research Foundation of Rio Grande do Sul (FEPAGRO), the Agricultural Research and Rural Extension Institute of Santa Catarina State (EPAGRI), the Agronomic Institute of Paraná (IAPAR) and at Technical Assistance and Rural Extension Corporations of Rio Grande do Sul and Paraná States (EMATER/RS and EMATER/PR). Among the most common and relevant topics observed in these studies were: tolerance of forage and agricultural species to shading; indication of timber and non-timber tree species for agroforestry systems; forest spacing and planting designs for agroforestry; tree productivity, interaction between trees, understory plants and grazing animals (cattle and sheep) in the systems; economic, environmental and social aspects of agroforestry; microclimate, water and nutrient relations within the systems; carbon balance and emission of greenhouse gases.

Another relevant observation in the past decade was the involvement of the private sector, mainly from the pulp and paper industries, with scientific and technical activities on agroforestry systems in cold regions of Brazil. The opportunity to increase plantation area, the regional culture on singular cropping or extensive livestock systems, and the increasing concerns about environmental issues, motivated forestry companies to initiate technical and financial collaboration with research institutions and extension to conduct applied research on the integration of forest-agriculture-livestock systems. In addition, from 2004, forestry companies started promoting partnerships with the State Government of Rio Grande do Sul and credit financial institutions to expand agroforestry areas using eucalyptus and several crops and forages in southern Brazil. It was during this period that the greatest increase in agroforestry planted area in southern Brazil occurred, estimated at 3 million hectares currently. These areas mainly involved the combination of eucalyptus with various agricultural crops (soybean [*Glycine max*], maize [*Zea mays*], sorghum [*Sorghum bicolor*], sunflower [*Helianthus annuus*], watermelon [*Citrullus lanatus*], wheat [*Triticum* spp.], barley [*Hordeum vulgare*]) with forage species grown (annual ryegrass [*Lolium multiflorum*], oats [*Avena* spp.], white clover [*Trifolium repens*], red clover [*Trifolium pratense*], birdsfoot trefoil [*Lotus cornicuatus*]), and ruminant animals (Fig. 10.2).

Models of integrating trees with agriculture and livestock, promoted by forestry companies in

Fig. 10.2 Agroforestry systems used in southern Brazil: integration between eucalyptus and sorghum [*Sorghum bicolor*] at VCP Company (*above* and *left*), sunflower [*Helianthus annuus*] (*above* and *right*); integration between eucalyptus (*Eucalyptus grandis*), tropical grass (*Brachairia brizantha*), eucalypt, grass temperate pasture and beef cattle at a smallholder property in Paraná State (*below* and *left*) and integration between black wattle and *Digitaria diversinervis* grass at FEPAGRO (*below* and *right*) (Images from: A.C. Varella; V. Porfirio-da-Silva; Z.M. Castilhos)

southern Brazil, had occurred before in the southeast part of Brazil, mainly in Minas Gerais and São Paulo. However, these models had serious limitations in performing as a long term system in this southern environment, particularly in Rio Grande do Sul, because of the high tree densities used (above 1000 trees per hectare) and radiation conditions with lower photoperiod and a different solar angle (maximum 38° in July) in the winter period than tropical areas. These conditions combined with the rapid early growth of eucalyptus, imposes heavy shading to understory plants at these latitudes. In addition, these agroforestry models failed to prevent excessive shading on understory by pruning and thinning trees at 4–5 years after forest establishment. This resulted in short term agroforestry integration, allowing ruminant grazing under trees only for the first 3 years after trees had been planted. Then the area turned into an exclusive forest plantation, allowing grazing only in the border areas. This fact has discouraged many farmers and producers from Rio Grande do Sul, who considered that this model would turn their traditional animal production systems into conventional forestry rather than long-term integration systems. In 2010, the forest development programs were discontinued in southern Brazil because forest companies and environmentalists disagreed about environmental issues raised by the government of Rio Grande do Sul that were aimed at permitting establishment of more plantations. Also the lack of firm positioning from State Government for the consolidation of forestry sector in southern Brazil discouraged advances in forestry investments. These factors caused forest companies to revise their strategic plans, quit the expansion of forestry and agroforestry areas, particularly in Rio Grande do Sul, and change their investments to the tropical and central region of Brazil.

Conversely, forestry investments were maintained similarly in Santa Catarina and Parana over the last 5 years. In these States, agriculture is predominant and area for expansion of conventional forestry investments is limited, nevertheless there is still land area for the expansion of agroforestry systems.

The situation will likely remain the same in the near future. The southern region of Brazil will experience a decrease in the supply of raw material for forest products, particularly to meet the demands of the furniture industry, sawn wood, medium density fiberboard (MDF) and particleboard, joinery and carpentry business, pulp and paper industry, tannins, resins, and chemicals derived from black wattle, posts and treated wood for construction, and wood for energy and charcoal. New debates for the resumption of forestry investments returned to the public agenda of governments, forestry managers, technicians, producers and more recently companies. This time, trying to establish a new strategy based on territorial and sustainable development, as required by a modern society, with production systems adapted to the environmental, cultural and productive conditions of the southern region. Clear rules and better integration for negotiating parties (government, environmentalists, farmers and companies) are needed to set a new cycle of forestry and agroforestry growth in southern Brazil. Therefore, agroforestry systems may provide a sustainable alternative to all parties, leading to new challenges for stakeholders and encourage the return of investments and expansion of agroforestry area in southern Brazil by private sector. To achieve that objective, some challenges must be addressed:

- Proposition of feasible models for forestry-livestock farming systems in contrast to the traditional agricultural cultivation, the extensive cattle and sheep rangeland systems and the specialization of forestry systems commonly used on farms and by companies in southern Brazil;
- Implementation of new programs promoting agroforestry, integrating public and private sector and encouraging the establishment of low tree density (below 800 trees/ha) systems and offering financial credit compatible with the length of time required to obtain wood in these systems. Forest companies should change their strategy and focus on increasing the planting area (suppliers) by attracting more farmers (mostly rangeland producers) with the proposition to establish integrated systems. Animal producers are generally resistant to conversion of rangeland systems to a long-term profit system such as forestry plantations;
- Reversal of the current situation of little knowledge and appreciation for the role of trees in farming systems (commercial, environmental, animal welfare, landscape) by reinforcing curricula in schools and universities;
- To implement public policies that support a strategy of territorial management using geo-spatial tools (satellite imagery and geo-referenced information system) capable of supporting decisions and rules for forestry and agroforestry business and reducing environmental concerns, particularly avoiding exceeded occupation of natural biomes in southern Brazil;
- Enhance the certification of forest products from sustainable systems such as agroforestry;
- Create massive technical training programs on agroforestry systems in the public and private sectors, associated with consulting firms, official technical assistance, rural extension, and cooperatives.

This chapter includes main results collected from agroforestry experiments in Rio Grande do Sul, Santa Catarina and Parana, including several C_3 and C_4 pastures (natives and exotics) performances under shade, beef cattle and sheep performance and behaviour under trees, climate-tree-pasture-animal interactions, and other relevant results from the last 20 years. As part of this challenge, this chapter aims to: (i) review the major scientific and technological advances in silvopastoral systems, with emphasis on silvopastoral systems developed by public and private institutions in southern Brazil; (ii) Report success cases from producers and forestry companies; (iii) propose alternatives for expanding the area of silvopastoral systems in southern Brazil in order to promote development with sustainable land management and providing opportunities to many services and multifunctional activities in farms, benefiting producers, industry and consumers involved in this chain.

10.2 Potential of Forage Plants for Silvopastoral Systems in Southern Brazil

The focus of research on silvopastoral systems in the late 1990s was to conduct experiments based on reductionist models, aiming to study binary interactions between the components of the integrated system, such as tree-pasture, soil-plant, plant-environment, etc. (Saibro 2001) and rarely contemplated the effect of the grazing animals (Saibro and Barro 2009).

Since then, a series of silvopastoral projects were developed with grasslands, which is an important and remarkable forage resource in the southern region of Brazil, particularly in Rio Grande do Sul State. These studies demonstrated that tree species, age, and density are factors that interfere with the growth of C_3 and C_4 species of the native grasslands. This occurs because of changes in light quantity and quality that passes through the trees. For example, Varella and Saibro (1999) found no differences on dry matter yield underneath three *Eucalyptus saligna* densities (816, 400 and 204 trees ha^{-1}) in the first and second years of a silvopastoral system at the experimental site of UFRGS. According to the author, the incident radiation was not limiting to understory vegetation because trees were approximately 2 m in height in this experiment. In addition, Fucks (1999), working at the same experimental site, reported decreases on grazing days, dry matter yield and stocking rates under the tree densities at years 3 and 4. In another UFRGS experiment, Silva (1998), working with winter pasture under *E. saligna*, reported that tree density influenced animal performance as pasture density and carrying capacity decreased, affecting beef cattle gains after the second year of tree establishment.

In the past, several studies focused on quantifying the effects of reduced radiation on the yield of understory pasture, seeking to determine limits of pasture growth and forage shade tolerance when altering tree densities. In these experiments, the shading levels were usually high after the second and third year as a consequence of the high tree populations established (800–1000 trees ha^{-1}), using fast growing trees and simple rows arrangement (Schreiner 1987; Silva et al. 1998; Fucks 1999; Varella and Saibro 1999; Lucas 2004). Despite these important advances, research on silvopastoral systems faced a discontinuation of support by financial agencies in the Brazilian subtropics and studies with a sequence of tree-pasture interactions in experimental sites were missed at that stage. Therefore, there is still lack of scientific information on pasture yield and management of silvopastoral system over the complete productive cycle of silvopastoral systems, particularly underneath fast growing tree species such as *Eucalyptus* sp. and *Pinus* sp.

The next step in silvopastoral research in southern Brazil was the investigation of the changes on pasture morphology, physiology, and nutritive value in response to shading, from the early 2000s (Barro et al. 2008; Soares et al. 2009). More recently, important scientific advances have been made in understanding the mechanisms of pasture adaptation and tolerance to shading from research groups in southern Brazil (Varella et al. 2011; Barro et al. 2012; Pontes et al. 2014; Baldissera et al. 2014). For instance, Pontes et al. (2014) and Baldissera et al. (2014) showed the relationship between soil N supply, plant height and light interception of six perennial tropical forages under trees, leading to important management practices of pasture intensity for silvopastoral systems. In addition, Barro et al. (2012) showed the N nutrition dynamics and forage yield of four important forages from southern grasslands in Brazil under shading and potential to use them in silvopastoral systems. This meant an extra step to better establish and manage pastures underneath trees and consequently, increase pasture productivity and quality in integrated systems.

The preliminary results indicated that more conservative management of pasture under shade has greater chances of success (longevity, yield, and quality) (Baldissera 2014). Overall, the management of understory pastures requires continuous investigation on silvopastoral systems in order to generate growth models as a function of available solar radiation and management applied. This would support pasture and grazing management decisions by farmers as trees develop in the system.

10.2.1 Overview of Forage Research in Shaded Environments

Grazing management can be established by controlling the frequency and intensity of defoliation (Pedreira et al. 2007). The combination of these variables greatly affects the structure of the pasture canopy (Da Trindade et al. 2007), which are also influenced by shading. However, only recently basic investigations concerning the influence of grazing management on shaded pastures and morphophysiological changes have been conducted in southern Brazil.

In agroforestry systems, grazing management should explore the phenotypic plasticity of forage species under shade. Scientists have recommended that forages under shade should be managed in order to maintain more residual leaf area or post-grazing heights greater than those in full sun. However, further studies on frequency and intensity of grazing pastures are required in silvopastoral systems, along with studies of pasture nutrient and water efficiencies in order to develop better pasture management strategies.

The interception of photosynthetically active radiation (iPAR) by the pasture canopy is the main variable used for determining the optimal timing for grazing defoliation (Silva and Carvalho 2005). In full sunlight, 95 % light interception by the pasture canopy results in optimum growth (Silva and Carvalho 2005; Da Trindade et al. 2007). Thus, consistent relationships between sward height on pre-grazing and iPAR by the canopy has being determined for several forage species in full sun (e.g. Zanini et al. 2012; Amaral et al. 2013), but rarely under shaded conditions. Finally, it has been pointed that this relationship may be different in silvopastoral systems than in open pastures as canopy photosynthesis decreases rapidly under shade and less carbon reserves are stored in roots (Barro et al. 2012; Varella et al. 2012). Therefore, more research also needs to be conducted to determine the optimum light interception point by pasture canopies under shade for cutting or grazing.

10.2.2 Perennial C_4 Forages

The adaptation of perennial forages to different levels of shading has been a target of many studies in Brazil for at least 20 years (e.g. Schreiner 1987). In the cold regions of the subtropics, tropical perennial forages stop growing during autumn and winter seasons and, eventually, susceptible genotypes are unable to survive over the frosty period in southern Brazil. The silvopastoral integration allows obtaining productive perennial C_4 pastures all year by minimizing climate extremes under the trees (Lucas 2004; Sartor et al. 2006; Kirchner et al. 2010). Even in the coldest areas of southern Brazil, where severe frosts are frequent from April to August, tropical pastures such as *Brachiaria* spp., *Panicum* spp. and *Cynodon* spp. can remain green and productive for longer periods under trees than they would tolerate in an open area (Fig. 10.3) and this represents an extraordinary feeding resource for cattle and sheep during extreme weather on farms.

Several studies have shown the potential yield of tropical forages under moderate shade in southern Brazil (Table 10.1). Research has shown the best growth responses, morphological and physiological adaptation and nutritive value of C_4 grasses under moderate shade (up to 40–50 % shading). In some cases, the shading effect may be very beneficial, resulting in higher dry matter yields compared to open pastures, especially in soil water and nitrogen deficit conditions,

Fig. 10.3 Experiment evaluation of *Panicum maximum* under *Eucalyptus* spp. (*left side*) and in full sun (*right side*) at FEPAGRO Unit in Rio Grande do Sul. Photos were taken at the same moment after a severe frosting event on September, 12th 2003 (Images from J. C. Saibro)

depending on tree density and type of soil. For example, recent studies have shown the unique response of *Paspalum regnellii* (Table 10.1), highlighting its potential yield under severe shading (up to 80 % shade) and the improvement of forage nitrogen content (Barro et al. 2012). As shown in Table 10.1, the study of C_4 perennial forages under shade is highlighted in southern Brazil because of the potential of early production in spring after the second year of establishment and high growth rates in summer when native and annual pastures are usually water stressed. Also, perennials are preferred by farmers over annual pastures for silvopastoral systems as the process of germination and emergence are difficult in shaded environments and pasture production costs are higher (Varella et al. 2011).

In addition to *P. regnellii*, other native grasses from Pampa and Atlantic Forest Biomes have shown potential for use in shaded environments. These species were initially identified at the transitional area between native forests and grasslands of southern Brazil, such as *P. regnellii* (Barro et al. 2012), *Axonopus catharinensis* (Soares et al. 2009; Barro et al. 2008) as well as forage species from open sites which showed high plasticity under shade, such as *Paspalum notatum* (Soares et al. 2009), *P. dilatatum* (Barro et al. 2012) and *Arachis pintoi* (Barro et al. 2014). However, further research advances with these perennial native forages, particularly evaluation under grazing, have faced difficulties because of the lack of seed of commercial cultivars in the market. Research institutions are putting great efforts into getting registration of these native forage cultivars by the Brazilian Ministry of Agriculture, Livestock and Food Supply and to establish seed fields of these cultivars to enable farmers to increase silvopastoral systems based on C_4 pastures.

10.2.3 Annual and Perennial C_3 Forages Adapted to Shade

Besides the perennial C_4 grasses, the animal production systems in southern Brazil are characterized by the cultivation of winter forage grasses. The most commonly grown pasture species used are annual ryegrass (Silva et al. 1998; Barro et al. 2008; Kirchner et al. 2010), forage oats-(Deiss et al. 2014) and the dual purpose cereals (wheat, barley, triticale and oats). Currently, these species are objects of research in various institutions (Table 10.2), in different production systems, with or without the presence of trees and with the possibility of being used in rotational systems, particularly with cash crops (soybean and maize) over the summer or composing an agroforestry system.

Table 10.1 Summary of C_4 pastures tolerance to shade from several studies in southern Brazil

Forage cicle	Carbon fixation	Growing season	Species	Shade level tested	Type of shading	Relative yield to full sun	Effect on nutritive value	References
			Axonopus catharinensis	24 and 56 %	Tree shade	52 and 50 %	Not determined	Barro et al. (2008)
				17 and 33 %	Tree shade	79 and 47 %	Increased	Soares et al. (2009)
				40 to 50 %	Tree shade	74 %	Not determined	Pontes et al. (2012)
			Cynodon sp. (cv.Tifton 85)	40 to 50 %[a]	Tree shade	25 and 50 %	Not determined	Pontes et al. (2012)
				24 and 56 %	Tree shade	61 and 51 %	Not determined	Barro et al. (2008)
				17 and 33 %	Tree shade	48 and 24 %	Increased	Soares et al. (2009)
			Brachiaria brizantha cv Marandu	17 and 33 %	Tree shade	86 and 36 %	Increased or mantained	Soares et al. (2009)
				40 to 50 %	Tree shade	45 %	Not determined	Pontes et al. (2012)
			Brachiaria decumbens cv. Basilisk	17 and 33 %	Tree shade	48 and 24 %	Not determined	Soares et al. (2009)
			Brachiaria decumbens	25, 50 and 80 %	Artificial shade	85, 44 and 22,7 %	Not determined	Schreiner (1987)
			Digitaria decumbens	25, 50 and 80 %	Artificial shade	88, 60 and 25 %	Not determined	Schreiner (1987)
			Panicum maximum cv. Aruana	17 and 33 %	Tree shade	54 and 9 %	Increased	Soares et al. (2009)
				40 to 50 %[a]	Tree shade	57 and 20 %	Not determined	Pontes et al. (2012)
Perennial	C4	Summer	*Panicum maximum* cv. Tanzânia	17 and 33 %	Tree shade	61 and 0 %	Not determined	Soares et al. (2009)
				not determined	Tree shade	25 %	Not determined	Ferreira et al. (2006)
			Panicum maximum cv. Mombaça	17 and 33 %	Tree shade	47 and 15 %	Not determined	Soares et al. (2009)
				not determined	Tree shade	22 %	Not determined	Lucas (2004)
			Paspalum notatum cv. Pensacola	17 and 33 %	Tree shade	87 and 26 %	Not determined	Soares et al. (2009)
				40 and 50 %	Tree shade	54 and 10 %	Not determined	Pontes et al. (2012)
				25, 50 and 80 %	Artificial shade	93, 55 e 13 %	Not determined	Schreiner (1987)
			Paspalum notatum	50 and 80 %	Artificial shade	112 and 81 %[a]	Increased	Barro et al. (2012)
			Paspalum dilatatum	50 and 80 %	Artificial shade	117 and 81 %[a]	Increased	Barro et al. (2012)
			Paspalum regnelii	50 and 80 %	Artificial shade	118 and 99 %[a]	Increased	Barro et al. (2012)
			Hemarthria altissima	25, 50 and 80 %	Artificial shade	99 and 22 %	Not determined	Schreiner (1987)
			Hemarthria altissima cv. Flórida	17 and 33 %	Tree shade	66 and 5 %	Not determined	Soares et al. (2009)
				40 to 50 %	Tree shade	7 %	Not determined	Pontes et al. (2012)
				24 and 56 %	Tree shade	58 and 43 %	Not determined	Barro et al. (2008)

[a]Under severe drought

Table 10.2 Summary of C_3 pastures tolerance to shade from several studies in southern Brazil

Forage cicle	Carbon fixation	Growing season	Species	Shade level	Type of shading	Relative yield to full sun	Effect on nutritive	References
				30 e 60 %	Tree shade	43 and 22 %	Increased	Kirchner et al. (2010)
			Lolium multiflorum	24 and 56 %	Tree shade	46 and 36 %	Increased	Barro et al. (2008)
				33 and 58 %	Artificial shade	87 and 84	Not determined	Saibro (1992)[a]
				30 e 60 %	Tree shade	38 and 13 %	Increased	Kirchner et al. (2010)
			Avena sativa	24 and 56 %	Tree shade	75 amd 42 %	Increased or mantained	Barro et al. (2008)
Annual	C3	inverno	*Avena strigosa*	30 and 60 %	Tree shade	43 and 8 %	Piora	Kirchner et al. (2010)
				24 and 56 %	Tree shade	75 and 42 %	Decreased	Barro et al. (2008)
			Holcus lanatus	50 and 80 %	Artificial shade	234 and 223 %[a]	Not determined	Varella et al. (2008)
			Bromus auleticus	50 and 80 %	Artificial shade	737 and 605 %[a]	Not determined	Varella et al. (2008)
			Bromus catharticus	50 and 80 %	Artificial shade	205 and 159 %[a]	Not determined	Varella et al. (2008)
			Triticum aestivum-duplo proposito	30 and 60 %	Tree shade	46 and 25 %	Decreased	Kirchner et al. (2010)
			Vicia villosa	30 and 60 %	Tree shade	48 and 27 %	Mantained	Kirchner et al. (2010)
			Arachis Pintoi (hybrid ecotype)	50 and 80 %	Artificial shade	93 and 60 %	Decreased	Barro et al. (2014)
Perennial	C3	verão	*Arachis pintoi* cv. Alqueire	17 and 33 %	Tree shade	37 and 18 %	Not determined	Soares et al. (2009)
			Arachis pintoi cv. Amarillo	17 and 33 %	Artificial shade	59 and 23 %	Not determined	Soares et al. (2009)
Perennial	C3	inverno	*Trifolium repens* cv. Zapicân	24 and 56 %	Tree shade	25 and 40 %	Decreased	Saibro et al. (2008)
			Lotus comiculatus cv. São Gabriel	24 and 56 %	Tree shade	27 and 25 %	Decreased	Saibro et al. (2008)

[a]Under severe drought

For this group of pastures, Porfirio-da-Silva (2012) found a decrease in forage yield in silvopastoral systems compared to full sun. For instance, the winter pastures *Avena strigosa* and *A. sativa* intercropped with *Lolium multiflorum* were evaluated in two integrated systems: with and without the presence of trees. Forage yield in full sun averaged 2524 kg DM ha^{-1} and was higher than under shade which yielded 2210 kg DM ha^{-1}. However, beef cattle liveweight gains were similar between the treatments, ranging from 0.55 to 1.10 kg LW day^{-1}. In addition, Kirchner et al. (2010) reported yields of several winter forages varying from 38 to 48 % under 15×3 m *Pinus taeda* system (30 % shade) and from 8 to 27 % under 9×3 m (60 % shading) compared to open pastures in Santa Catarina State. Likewise, annual ryegrass performance was highlighted in this study, yielding 3478 kg DM ha^{-1} and showing 18 % of total crude protein under the 15×3 m system.

The responses of C_3 legumes on DM yield and nutritive value are individual and dependent on their agronomic performance under shade. Results as to the quantitative and qualitative performance of winter forage legumes in single or mixture pastures and under different shading levels were obtained in the subtropics (Table 10.2). For example, white clover (*Trifolium repens*) and birdsfoot trefoil (*Lotus corniculatus*) yields were similar under 15×3 m *Pinus taeda* system (moderate shading) compared to full sunlight (Barro et al. 2006) growing on a sandy soil of the coastal area in Rio Grande do Sul State. In a different experimental site, Sartor et al. (2006) reported that birdsfoot trefoil yielded 2844 and 2669 kg DM ha^{-1} under the 15×3 m and 9×3 m *Pinus taeda* system, respectively, whereas in an open pasture yielded 8121 kg DM ha^{-1} on clay soil of Santa Catarina State. In sequence at the same experimental site, Kirchner et al. (2010) showed that the annual legume forage *Vicia villosa* yielded 2300 kg DM ha^{-1} under intermediate shade (15×3 m) and 1292 kg DM ha^{-1} under the heavy shade (9×3 m) compared to 4771 kg DM ha^{-1} in full sun. In artificial shade conditions, Barro et al. (2010) reported that *Arachis pintoi* yield was affected by intense shade (80 %), but still showed potential to increase nutritive value of natural grass-legume mixtures under intermediate (50 %) shade level. Under intense shading (80 %), *Arachis pintoi* showed a decrease of 40 % in dry matter yield compared to full sun. However, under moderate shading (50 %), this legume performance was not affected (Table 10.2).

The performance of forage legumes at different levels of radiation has shown that these are usually less shade tolerant than grasses (Watson et al. 1984; Barro et al. 2012), although this is not necessarily a rule (Johnson et al. 2002) and may change under soil nitrogen stress. The large, productive and reproductive success of forage legumes in agroforestry depends on their ability to adapt to decreasing levels of light with tree canopy closure with advancing age (Balocchi and Phillips 1997). Physiologically, the forage legumes operate as C3 plants, and could potentially support shading at intermediate levels. However, quite different responses have occurred with regard to the agronomic performance of forage legumes under shade. There is still inadequate scientific information regarding the performance of legumes under shade in subtropical environments of Brazil (Varella et al. 2009).

10.3 Potential of Trees for Silvopastoral Systems in Southern Brazil

The trees most commonly used in silvopastoral systems in cold regions of Brazil are species adapted to climate and soil conditions of the region, with relatively rapid growth rate (about 2 m high per year) and with great value of the wood in the market (Table 10.3). Historically the integration of beef cattle with forests date from the mid-eighteenth century (Chang 1985), known as traditional "faxinais" systems, mainly established in the area of occurrence of Araucaria native forests (*Araucaria angustifolia*). The first studies of silvopastoral systems in the Brazilian subtropics sought to utilize livestock as a secondary component of the system. Cattle were introduced in conventional tree plantations as a strategy to improve cash flow in the early years of

Table 10.3 Predominant tree species applied in silvopastoral systems in cold zones of Brazil

Number of frost events	Tree species or hybrids used in silvipastoral systems	Tree species tested in experimental studies
0–1	*Eucalyptus urophylla*; *E. urophylla x E. grandis*; *Corymbia citriodora*; *C. camaldulensis*;	Tropical Pinus (Gutmanis 2004)
		Native species (Melotto et al. 2009; Nicodemo et al. 2010)
0–5	*E. grandis*; *E. urophyllax E. grandis*;*C. citriodora*; *C. camaldulensis*; *Grevillea robusta*;	Native species (Melotto et al. 2009; Nicodemo et al. 2010)
		Kaya ivorensis e *Toona ciliata* (Porfírio-da-Silva et al. unpublished data)
		Leucaena spp. (Sampaio et al. 2009)
≥5	*E. dunnii*; *E. benthamii*; *Acacia mearsii*;*E. grandis*; *E. saligna*; *Grevillea robusta*; *Araucaria angustifolia*	Native species (Radomski and Ribaski 2010; Porfírio-da-Silva et al. 2012)
		Populus spp. (Otto et al. 2009)
		Pinus elliotti (Ribaski et al. 2005)
≥20	*E. benthamii*; *Pinnus taeda*; *P. elliottii*; *Araucaria angustifolia*	*Pinus taeda* (Soares et al. 2009)

forest cultivation, besides getting the benefits of controlling the development of unwanted plants in the understory and reducing the risks of fire inside the forest (Baggio and Schreiner 1988; Schreiner 1994; Varella and Saibro 1999; Silva et al. 2001).

Although there is potential for use of many other tree species, *Eucalyptus* spp. is the most commonly planted one in cold regions of Brazil, followed by *Grevillea robusta* (Martins et al. 2015), *Acacia mearsii*, and subtropical Pinus spp. The genus Eucalyptus is important for Brazil because of the raw material for pulp production, coal, wood, panels, posts, poles, sawn timber, furniture, packaging and other commercial uses. This tree species and its different cultivars are well adapted to southern Brazil conditions and can compose silvopastoral systems in almost all territories. In Zones 1 and 2 (Fig. 10.2), successful plantings have been carried out with hybrids between *Eucalyptus grandis* x *E. urophylla*; especially in the western portions of these zones, where frequent droughts can also occur during the summer and autumn seasons. Because of the rapid growth of these hybrids during the first spring and summer seasons, plants can tolerate the cold temperatures in the first winter period. *E. grandis* has been planted successfully in the southern portions of Zone 2 and north- northwest of Zone 3 (Higa and Wrege 2010), except on the coastal area where the species may be affected by various diseases caused by high relative humidity (Alfenas et al. 1983). The *Corymbia citriodora* and *C. camaldulensis* species has also been observed in silvopastoral systems across Zone 2, except at the coastal area where the tree-pasture systems are rare. The *E. benthamii* and *E. dunnii* are more tolerant to low temperatures and this is the main reason for them to be widely planted in silvopastoral systems of Zone 3. *E. benthamii* is the most tolerant species to frosts among all species of Eucalyptus sp. (Jovanovic and Booth 2002; Paludzyszyn Filho and Santos 2013) and has been planted in Zone 4. *E. saligna* also has been planted in integrated systems in this area (Silva 1998; Varella 1997). In addition to *E. benthamii*, subtropical species of pine (*Pinus elliottii* and *P. taeda*) have also been used for silvopastoral systems in Zone 4. These pines have also been planted in Zone 3 of southern Brazil.

In Brazil, soil and water conservation is a priority when planning the introduction of trees into pastures. This means that the orientation of the tree rows during system establishment must be a priority in order to promote soil and water conservation. Observation of the apparent path of the sun in the sky to orient the arrangement of tree rows is secondary to consideration of soil and water conservation issues. The solar energy that reaches the land in cold zones of Brazil is high, ranging from 4 to 6 kW.hm^{-2} (Ceballos and Bottino 2006). The region where the incidence of solar radiation is lowest (4.5 $kW.hm^{-2}$) partially coincides with Zone 4 in Fig. 10.2, and it is distributed along to the coastline and nearby Itajai River valley, and this fact has been associated with increasing cloudiness in these regions.

The spatial arrangement of trees is critical for the success of a silvopastoral system. Establishment is facilitated by proper spatial distribution of trees in the field and this should aim to promote soil and water conservation, favor the transit of machines and benefit ruminants' thermal comfort. According to several experiences in Brazil (Table 10.4), the most effective arrangement is the alleys, where trees are planted in strips (single or multiple rows) with wide spacing between strips. This basic arrangement can also be adjusted according to the commercial use of wood (Porfirio-da-Silva et al. 2009). For the tree component, there basically are two primary considerations in a silvopastoral system: (i) production of a great volume of fine wood (firewood, charcoal, stanchions, podiums, etc.) in the initial part of the trees rotation (i.e. about 6 years for Eucalyptus sp.). In this case, establishment should use the highest number of trees per area possible without limiting understory growth, usually between 600 and 1000 trees per hectare; and (ii) production of thick wood (for sawmill, rolling, etc.) in the final part of trees rotation (over 10 years old, depending on species and site) by planting few trees per area, i.e. about 250 trees per hectare. The different arrangements may be planted more closely spaced and managed by thinning trees over the development period to produce wood for different purposes (thin wood in the early years of the silvopastoral system and timber in the final years of the rotation).

In cold zones of Brazil, silvopastoral systems are commercially oriented and the predominant tree species used are grown to produce wood products (Table 10.3). The productivity and the quality of tree products in silvopastoral systems depends on the genetics involved (trees, forage crops, and livestock), the quality of the site (climate and soil), the spatial arrangement of trees, and management practices applied on arboreal, forage and animal components. Few studies have analyzed the productivity and quality of tree components in silvopastoral systems compared to conventional plantations in southern Brazil. For example, a 4 year silvopastoral system initiated with the goal of producing wood logs at 424 trees ha^{-1} showed mean annual increment of 33.2 m^3 ha^{-1} $year^{-1}$, whereas for the clone *E. urophylla* × *E. grandis* on a monoculture at 1111 trees ha^{-1} was 43.5 m^3 ha^{-1} $year^{-1}$. In terms of biomass produced in the system at 1111 trees ha^{-1} was the most productive. However, the volume per tree at 424 trees ha^{-1} was the greatest at 0.313 m^3 per tree, whereas at 1111 trees ha^{-1} volume reached only 0.156 m^3 per tree (Medeiros, unpublished data).

10.4 Animal Performance and Behaviour under Trees

The use of grazing animals in commercial forests must be planned taking into account that these activities require distinct management strategies. These integrated systems aim to improve production per unit area, whereas respecting the principle of sustained yield, maintaining the productive potential of renewable natural resources, and social and economic conditions of the local community (Silva and Saibro 1998). However, within a systemic view, the animal component demands attention because the positive interaction between

Table 10.4 Regular tree spacing and arrangement applied in silvopastoral systems in southern Brazil

	Thin wood (charcoal, firewood, fence posts)			Logs (timber)		
Tree arrangement	Tree spacing (m)	Trees per ha[a]	% Area occupied per row	Tree spacing (m)	Trees per ha[a]	% Area occupied per row
Single row	14×2	357	14	14×4	179	14
Single row	14×2	357	14	28×4	89	7
Double row	14×2×3	417	25	18×3	185	11
Triple row	14×3×1.5	1000	40	20×3	167	10

[a]Tree mortality was not included over the time (Adapted from Porfírio-da-Silva et al. 2009)

tree-animal-pasture in a silvopastoral system is driven by correct decisions with regard to stocking rate or grazing intensity and this is related to carrying capacity of understory pastures, as well as grazing behavior.

10.4.1 Animal Behavior and Performance under Eucalypt-Pasture Systems

The first study of animal performance in a silvopastoral system with eucalyptus in Rio Grande do Sul State was conducted in an area of 180 ha and tree spatial arrangement of 2×3 m. From June 1992 to March 1993 a test with 87 zebu heifers, up to 2 years old and average liveweight of 221 kg was conducted during which the animals were rotationally grazed. The animals gained 0.567 kg per day with a gain per area of 12.55 kg ha^{-1} (Silva et al. 1993). The total global radiation at the ground level inside the system ranged from 18 % in summer to 22 % in winter, compared to full sunlight (Ferreira et al. 1993). The forest allowed better environment for animal welfare, because, as compared to open pasture, temperature was warmer in winter and cooler in summer (Krause et al. 1993).

In another study, the impact of cattle and sheep grazing during the establishment phase of an *Eucalyptus saligna* forest with different tree densities was evaluated (204, 400 and 816 trees ha^{-1}) in the Central area of Rio Grande do Sul (Varella 1997; Varella and Saibro 1999). The authors concluded that the damage caused by cattle and sheep to trees was severe when tree height was less than 182 cm for weaned calves and 154 cm for lambs. Therefore, grazing could start at 6–7 months of eucalypt age in this region. This study also showed that cattle frequently caused damage by chewing leaves and tips of lateral or apical branches, trampling seedlings, and by rubbing or scratching seedlings. The previous experience of the animals to graze under these systems and the availability and quality of understory pasture also affected the extent of damage to seedlings. The authors concluded that animals could work as efficient biological tools to control herbaceous competition to seedlings at the establishment phase and this would be more economical than the use of pre and post emergent herbicides, in addition to reducing the risks of fire inside the forest. In a subsequent study, the impact of grazing on the growth of *Eucalyptus saligna* over the establishment phase was evaluated. Fucks (1999) showed that sheep grazing grassland under trees with an offer of 10 % (i.e. 10 kg of DM per 100 kg LW per day) resulted in significant increase in tree height and diameter at breast height (DBH) and this produced a greater volumetric increment rate and better quality of forest product at the three eucalypt densities. These results showed a benefit of animal presence and positive effects on tree development due to a decrease of understory herbaceous competition.

In the central area of Rio Grande do Sul, Silva et al. (1998) studied the effects of three grazing intensities (forage allowance of 6 %, 9 % and 13 % i.e. 6, 9 and 13 kg of pasture dry matter per 100 kg LW per day) and two eucalypt densities (1666 and 833 trees ha^{-1}) on animal behavior and performance (Fig. 10.4). This experimental site consisted of *Eucalyptus saligna* and annual ryegrass (*Lolium multiflorum* L.) + arrowleaf clover (*Trifolium vesiculosum* Savi cv. Yuchi) overseeded on native pasture. Continuous grazing with steers started when trees were at an average of 2.30 m height (9 months old) and stocking rates were adjusted monthly according to forage supply. The author reported that survival and growth of trees (tree height and diameter) were not affected by stocking at all grazing intensities and tree densities. Only 4.4 % of trees were damaged by steers, but without affecting further tree growth. It was shown that grazing management in silvopastoral systems, without limiting forage intake and quality of available forage, resulted in good animal performance and tree development. In addition, the mean daily gain (MDG) of steers was represented by a linear model, whereas the mean gain per area (MGA) was a curvilinear relation under 1666 trees ha^{-1} (Fig. 10.4a). Under the 833 trees ha^{-1}, both MDG and MGA were fitted by curvilinear models (Fig. 10.4b). Silva

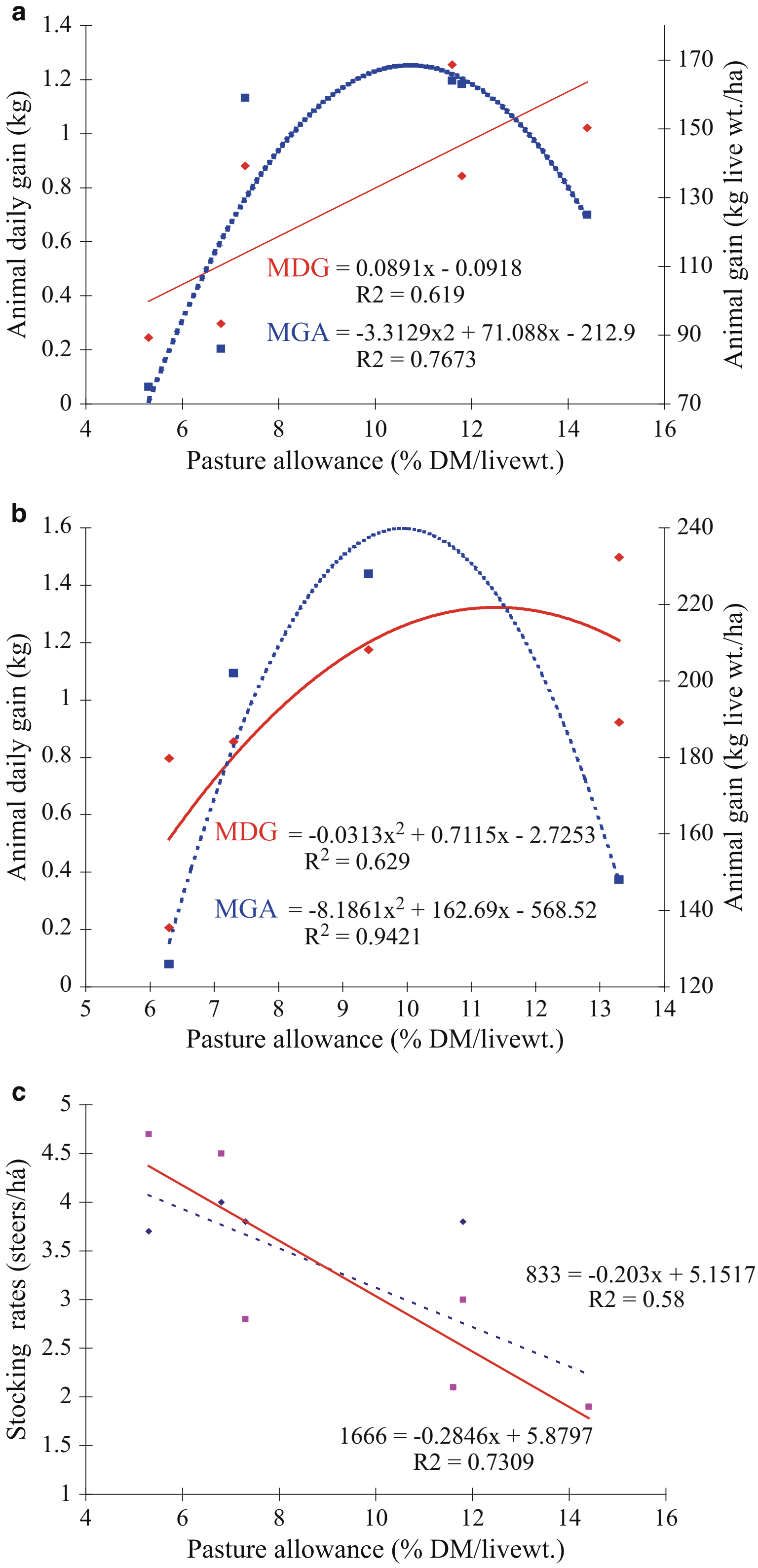

Fig. 10.4 Relationship between mean daily gain (*MDG*) and mean gain per area (*MGA*) with pasture allowance (kg DM per 100 kg liveweight) under 1666 (5a) and 833 (5b) eucalypt trees per hectare and respective stocking rates (5c) in a silvopastoral system with eucalypt, annual ryegrass and arrowleaf clover (*Trifolium vesiculosum*). Data are average of three replicates collected from 6th September and 9th November 1995 at UFRGS

(1998) concluded that gain per animal in a silvopastoral system increased with forage supply. The gain per area decreased at the lowest pasture allowance because of reduced individual performance by animals. Above 11 % of pasture allowance, MGA was also reduced due to low stocking rates (Fig. 10.4c). At intermediate stocking rate the optimum animal LWG per head and per area were obtained. For instance, the animal performance was about 220 kg LWG per ha at 10 % of herbage allowance during the first grazing period (i.e. 64 grazing days) under 833 trees ha^{-1}. In contrast, under 1666 trees ha^{-1}, animal performance was 161 kg LWG per ha at the same grazing intensity level. The best animal performance obtained in 2 years of experiment time was 455 kg LWG per ha under 833 trees ha^{-1} with stocking rates adjusted to 10 % of pasture allowance. This performance was 108 % higher than under 1666 trees ha^{-1}, showing the importance of low densities to get best results in silvopastoral systems. As a reference, average animal production on open native pastures is about 70 kg LWG per ha per year at the same location in southern Brazil (Maraschin 1998). Under the lowest tree population, animal production was 30 % greater than the highest tree population in the first year after tree establishment and this result doubled by the second year of the experiment. In addition, grazing was interrupted under 1666 trees ha^{-1} at tree age of 1.5 years, mainly due to strong shading to understory pasture (Silva et al. 1996). The conclusion of this study was that optimum pasture allowance in a silvopastoral system ranged from 9 to 11.5 % (Silva et al. 2011), whereas in open grasslands of southern Brazil, ranges between 9.5 and 12 % have been reported (Moraes et al. 1995; Maraschin 1998).

10.4.2 Animal Behavior and Performance under Black Wattle-Pasture Systems

The first study involving cattle grazing under black wattle was conducted in a commercial forest at 2 years old during winter period in Rio Grande do Sul State in 1992. The conclusions of this work were: (i) beef cattle were well adapted under the Acacia forest and were harmless to trees when stocking rates were controlled at intermediate levels; (ii) the integration of forestry and cattle grazing was profitable, showing a mean gross margin of 6.28 %; (iii) the costs of maintaining the forest and livestock are minimized by sharing infrastructure and human resources.

In 1995, a long-term experiment was established by the Rio Grande do Sul State Foundation for Agricultural Research (FEPAGRO) in collaboration with UFRGS and a private forestry company. This study was located in Tupanciretã (RS) with the aim to evaluate the interactions at soil-plant-animal-microclimate interface in a silvopastoral system with two populations of *Acacia mearnsii* and three understory C_4 pastures: *Brachiaria brizantha*, *Panicum maximum* cv. Gatton, and grassland infested by Annoni grass (*Eragrostis plana*), an undesirable weedy species. Beef cattle grazed pastures continuously with stocking adjustments to maintain pasture allowance between 10 and 12 %. The results showed 66 kg LWG per ha grazing on *P. maximum* and 33 kg LWG grazing on *B. brizantha* pastures during 63 days in winter under a 2×3 m *Acacia mearnsii* forest. In contrast, mean gain per ha increased to 75 and 60 kg grazing *P. maximum* and *B. brizantha*, respectively, under a

Table 10.5 Average daily gain (LWG) per animal and per hectare and stocking rate in silvopastoral systems with black wattle and perennial C_4 pastures grazed for 63 days in the winter

Understory pasture	Tree density					
	1667 trees ha^{-1} (2×3 m)			1000 trees ha^{-1} (2×5 m)		
	Kg LWG (per day)	Kg LWG (per ha)	Heads/ha	Kg LWG (per day)	Kg LWG (per ha)	Heads/ha
P. maximum	0.536	66	2.2	0.627	75	2.6
B. brizantha	0.750	33	1.6	0.726	60	2.8

Data are averages of two replicates. FEPAGRO experimental site in Tupanciretã/RS (Castilhos et al. 1999)

2 × 5 m Acacia forest (Table 10.5). These systems proved to be efficient during the winter season when beef cattle usually lose LW in open grasslands of southern Brazil. Over summer, animal performance under trees increased to 169 and 195 kg LWG per ha under the 2 × 5 m Acacia forest grazing *P. maximum* and *B. brizantha*, respectively (Table 10.6). The authors concluded that the silvopastoral systems with black wattle were sustainable, showing potential increase in animal production and income, particularly at low tree densities, for beef farms in Rio Grande do Sul.

At year 6 in this study, both tree densities were thinned to 50 % of the original population and *B. brizantha* and *E. plana* pastures were replaced by *Panicum maximum* cv. Aruana and *Digitaria diversinervis*, respectively, in the experimental plots. At this stage, Castilhos et al. (2009) reported that black wattle showed similar volume production (m^3 ha^{-1}) with or without grazing at 7 years after planting. For instance, Castilhos et al. (2009) showed that the volume of wood produced at this experimental site was 166, 143, 86 and 51 $m^3 ha^{-1}$ under the Acacia populations of 1667, 1000, 833 and 500 trees ha^{-1}, respectively. In addition, animal performance on *D. diversinervis* showed the greatest daily liveweight gain of all pastures as a result of higher nutritive value compared to *P. maximum*. However, this C_4 pasture provided the lowest grazing-days as a result of a remarkable decrease in pasture yield during the water stress period occurred in summer. According to the authors, this result explained the lowest liveweight gain per area and carrying capacity of *D. diversinervis* of all pastures under trees. In contrast, both *P. maximum* cultivars showed greater carrying capacities and gains per hectare compared to *D. diversinervis* (Table 10.7). The conclusion of this study was that silvopastoral systems using populations of *Acacia mearnsii* lower than 833 trees ha^{-1} compromised wood production, whereas increased animal performance grazing underneath C_4 pastures. From this work, it was also shown that Annoni Grass (*E. plana*) was shade intolerant. Several authors report Annoni Grass as the main weed that degrades southern Brazil rangelands and occupy about 20 % of the total area. Therefore, the tree-pasture systems become a sustainable alternative to recover those infested areas by using shade tolerant pastures combined to trees.

Finally, there is still a lack of scientific information on grazing behavior and animal welfare measured under silvopastoral systems. In the cold subtropical area of Brazil, livestock face extreme temperatures in winter and summer. Tree protection combined with accumulated forage may be strategic for sheep, dairy and beef farms which usually lose production at these stages. In the near future, this information may be available because a recent long term experimental site has been initiated at EMBRAPA South Livestock aiming to recover degraded grasslands by Annoni Grass and to evaluate thermal comfort of Brangus (Angus × Nelore cattle breed) at critical climate periods under silvopastoral systems.

10.4.3 Animal Behavior and Performance under Mixed Tree Crop-Livestock System

In southern Brazil, integration of trees, crops, and livestock in rotational systems are still unusual. Experiences have been applied by forestry companies and farmers more recently. This usually involves rotational systems between annual crops (maize, soybean, Sorghum spp., winter cereals), annual fruits (watermelon, melon, pumpkin) and pastures under spaced eucalypt plantations (Balbino et al. 2011; De Melo 2012). Likewise, experiments on mixed tree-crop-livestock systems have become frequent in scientific institutions of southern Brazil. For instance, an experiment with crop-livestock-forestry integration, using a mixture of tree species and winter pastures has been conducted since 2006 in Parana State. The tree components were *Eucalyptus dunnii*, *Schinus terebinthifolius* and *Grevillea robusta* and this was implemented in the Model Farm Station of IAPAR (Porfírio-da-Silva 2012). The trees were planted in an alternate arrangement within the row. The spatial arrangement was simple rows, with spacing of 14 m × 3 m, allocated across the predominant direction of the slope due to soil conservation issues. Since tree establish-

Table 10.6 Pasture residual dry matter (RDM), average daily gain (ADG), average gain per area (AGA), pasture carrying capacity (CC) and stocking rate (STOCK) in silvopastoral systems with two densities of black wattle and three C_4 pastures

Understory pasture	Tree density									
	1666 trees/ha (2×3 m)					1000 trees/ha (2×5 m)				
	RDM (kg/ha)	ADG (kg/hd/day)	AGA (kg/ha)	CC (kg/ha/day)	STOCK (hd/ha)	RDM (kg/ha)	ADG (kg/hd/day)	AGA (kg/ha)	CC (kg/ha/day)	STOCK (hd/ha)
P. maximum cv. Gatton	2422A[b]	0.644A	104	372	1.70	3200A	0.696A	169	520	2.55
B. brizantha cv. Marandu	1720B	0.573AB	105	394	1.85	2995A	0.690A	195	698	1.85
E. plana	1182B	0.539AB	95	418	1.80	1417B	0.417B	122	741	3.25
Mean[a]	1775a	0.585a	101a	395a	1.78a	2537b	0.601a	162b	653b	2.55b

Pasture allowance was maintained between 10 and 12 % during the period of 13th November 1998 to 18th February 1999. Data are averages of two replications. FEPAGRO experimental site in Tupanciretã/RS (Silva et al. 1999)

[a]Means followed by the same letter in the row, between the tree densities, do not differ at 5 % probability level by Duncan test

[b]Means followed by the same capital letter in the column, for pastures and tree densities interactions, do not differ at 5 % probability level by Duncan test

Table 10.7 Average daily gain (ADG), Average gain per area (AGA), average daily gain per area (ADGA), grazing-days per hectare (GD) and real pasture allowance (PA) in silvopastoral systems with two populations of *Acacia mearnsii* and three C_4 pastures

Pasture	ADG[a]	AGA[a]	ADGA[a]	GD[a]	PA
	kg/hd	kg/ha	kg/ha/day	An.day/ha	kg DM/100 kg LW
P. maximum cv. Gatton	0.738 a	337.6 a	3.13 a	445.5 a	13.9 a
P. maximum cv. Aruana	0.799 a	328.2 a	3.04 a	406.3 a	11.9 a
D. diversinervis	0.844 a	289.7 a	3.11 a	333.9 a	9.4 a
Mean	0.794	318.5	3.09	395.2	11.7

Pasture allowance was maintained at 12 % between 1st December 2003 and 18th March 2004. Data are averages of the two tree densities and replications. FEPAGRO experimental site at Tupanciretã/RS (Lucas 2004)
[a]Means followed by the same letter in the column do not differ significantly by the F test at 5 % probability

ment, the underneath area has been managed with corn and soybeans for grain production in summer and under a no till system. In winter, a mixture of black oats and annual ryegrass pastures (*Avena strigosa* and *Lolium multiflorum*) has been sown in sequence to summer crops. This experiment evaluated two levels nitrogen fertilization (90 kg ha^{-1} and 180 kg ha^{-1} N) on understory pasture. In this agroforestry system, grazing started at 41 months of trees age. At this stage the author reported that all tree species received damage by cattle, but severity was great only on *S. terebinthifolius*, therefore this tree species was considered unsuitable for integration systems (Porfirio-da-Silva et al. 2012). When trees were 29 months old, corn yield was similar under the three systems, with a mean grain production of 4.1 ± 0.3 ton ha^{-1} and mean increment of wood production was 1.03 m^3 per hectare over the corn cycle. In addition, the productivity of a soybean crop under trees at 56 months of age was 3.7 ton grain ha^{-1} or 19 % less than in crop-livestock integration conducted in an adjacent area, whereas the increase in wood production was 6.6 m^3 ha^{-1} over this crop cycle. The mean pasture DM yield was 2210.3 kg ha^{-1} and the mean daily gain of steers was 0.86 ± 0.31 kg ha^{-1} day^{-1} or 440.6 ± 75.9 kg ha^{-1} over the two grazing cycles (Porfirio-da-Silva 2012). The author observed that fertilization of winter pastures combined with the maintenance of a residual pasture height of 20 cm was essential for cattle production and strategic for no till management of summer crops.

10.5 Challenges for Research, Development and Technology Transfer on Silvopastoral Systems

Silvopastoral systems are dynamic and complex, particularly when considering the multiple interactions between trees, pasture and livestock in time and space (Balbino et al. 2011). The experience of implementation of integrated crop-livestock-forest systems in the last 25 years indicates the need for new and adapted models of production, technical assistance and rural extension for assuring the sustainability of Brazilian agriculture. To achieve that, it is important that research institutions conduct long-term experiments to investigate and transfer technologies to farmers and technicians continuously. Therefore, it is imperative that institutions develop joint programs for Research and Development (R&D) and Technology Transfer in silvopastoral systems since trees establishment period to the harvest of forest products. In addition, it is also important to understand that public and private technical advice require more training and qualification to manage these dynamic and sustainable systems.

In southern Brazil, the potential areas for silvopastoral systems are usually the ones currently occupied with extensive beef cattle and sheep extensive systems. To increase interest in this type of integration, it is essential that R&D offer suitable models that match producer interests and needs of the region. In this respect, issues related to animal welfare, the strategic forage supply during periods of extreme weather, and soil conservation should be highlighted in R&D programs. Besides, the self-consumption of wood in rural properties for energy and constructions, as well as for direct sale may also attract livestock producers to adopt these integrated systems. Therefore, the following opportunities and challenges for research and technology transfer in silvopastoral systems in southern Brazil are:

- To study new designs and spacing between trees for silvopastoral systems to allow minimum radiation level of 50 % on understory plants throughout the tree cycle;
- To offer alternatives of perennial and annual forage species and mixtures tolerant to shade, as well as climate and soil conditions in southern Brazil;
- To develop new forage cultivars adapted to shade;
- To quantify the benefits of shading for animal welfare (thermal comfort, performance and grazing behavior);
- To find profitable alternatives for selling or processing of timber and other forestry products from low tree density systems;
- To develop genetic improvement of trees for integration systems, highlighting plant architecture, biological cycle and quality of harvesting product;
- To develop silvopastoral system models involving native trees and forage species to meet requirements of the Brazilian environmental laws (legal reserves) on farms;
- To improve management of farms using silvopastoral systems;
- To develop and implement new training programs for technical and extension staff for silvopastoral systems on farms;
- To quantify environmental benefits provided by silvopastoral systems (carbon balance, mitigation of greenhouse gases, soil and water conservation);
- To develop soil nutrient tables to support annual fertilization decisions for tree-pasture systems;

Besides long term experimental areas and continuous research support from agencies, it is important that institutions invest in multidisciplinary teams, capable of responding to the opportunities and challenges mentioned. Important research institutions in southern Brazil, such as units of EMBRAPA, Federal Universities, and State Research Organizations should cooperate to achieve these goals as quick as possible. A collaborative network of scientists, extension agents, and consultants should develop demonstrative areas on farms for continuous training and technology transfer developed by research institutions. Currently, in southern Brazil, there is a reasonable physical structure available for national and international research institutions able to carry on long term and collaborative works on silvopastoral systems located at different sites on this region, such as:

- The silvopastoral system experimental site located at EMBRAPA South Livestock Systems (CPPSUL): established in 2013 and located in Bagé, Rio Grande do Sul State, border area with Uruguay. It's an area of 34 ha, containing three levels of radiation on the native pasture (full sun; 800 and 400 trees ha^{-1}), subdivided into two management systems (an intensive system using improved pasture with cool season forage species (annual ryegrass, red clover and birdsfoot trefoil) and a high fertility soil opposed to a conservative system using selective application of herbicide and livestock rate control) with the aim to recover degraded native pasture infested by the Annoni Grass weed (*Eragrostis plana*). The *Eucalyptus grandis* trees were established in triple rows spaced 2 m between plants and 3 m between rows. The spacing between the triple rows is 34 m or 14 m, resulting in a model of 3 × 2 × 34 m and 14 × 3 × 2 m.
- The experimental Farm Canguiri of the Federal University of Paraná (UFPR): located in Pinhais City, State of Parana. This area uses different integration models in order to obtain results over the complete cycle of the system: (i) integrated crop-livestock-trees system; (ii) crop-livestock system; (iii) Livestock-trees system; (iv) Crop-tree system and (v) integrated tree-pasture system. The trees were planted in single rows with *Eucalyptus*

benthamii spaced 14 m between rows and 2 m within the rows at an initial density of about 250 trees ha^{-1}. For comparative purposes, there is still a monoculture system (plantation) established with at 3 × 2.5 m, resulting in an initial density of 1333 trees ha^{-1} and a final density of 800 ha^{-1}.

- The Model Farm of the Agronomic Institute of Paraná (IAPAR): located in Ponta Grossa City in the South Central Region of the Paraná State. This experimental site has three major areas of study:(i) an experimental area for crop-livestock-tree system. It was established in 2006 with *E. dunnii*, *Schinus terebinthifolius* and *Grevillea robusta* trees, planted in single rows and spaced at 14 × 3 m, resulting in 238 trees ha^{-1}. In 2013 the *S. terebinthifolius* was removed from experimental area because leaves and branches were noticed to be palatable to grazing animals, therefore barking and chewing became limiting for the integration (Porfírio-da-Silva et al. 2012). The total area of the experiment comprises 10.9 ha and was splitted into six paddocks of crop-livestock integration and other six of tree-crop-livestock system. Over the cool season, the pasture areas between trees rows were sown with a mixture of forage oats and annual ryegrass for grazing, followed by soybeans and maize in summer; (ii) to make experiments in plots with understory plants and between the double rows of *Eucalyptus dunni*. It was established in 2007 in the density of 330 trees ha^{-1} (21 × 4 × 3 m). After thinning in 2011, the density decreased to 155 trees ha^{-1} (Pontes et al. 2012).; (iii) to make experiments with different densities and spatial arrangements of trees, *Eucalyptus benthamii* was established in 2008 in single, double and triple rows of trees. The spacing between rows is 21 m, resulting in the following spatial arrangements: 21 × 2 (single line); 21 × 2 × 3 (double line) and 21 × 2 × 3 (triple line).

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